Editorial

The Makings of A Great Electrochemist

MICHAEL FARADAY was one of the great scientists. His contributions to fundamental electrochemistry probably equal or exceed those of any investigator since his time. The quantitative relation of electricity to chemical change, worked out in accurate detail, made a science of what was previously a group of hazy ideas. From his work, it followed that the ampere could be defined precisely by the amount of silver electrodeposited in a given time, and this also established a fundamental constant expressing quantity of electricity per chemical equivalent. Still later this constant, appropriately named the Faraday, was combined with Millikan's determination of the charge on the electron to give the first accurate measure of Avogadro's number. The succession of scientific events resulting from Michael Faraday's electrochemical experiments cover a broad spectrum.

Sir Humphrey Davy's greatest discovery, it is said, was Michael Faraday. On the other hand, Michael Faraday's greatest discovery was *Michael Faraday*, according to Samuel E. McCrary writing in the November *Technology Review*, for self-discovery was perhaps the most important factor in Faraday's success. The well-deserved praise recorded of Faraday's scientific discoveries far overshadow current records of the precepts which guided him in daily life, and of the techniques which he learned to apply in his scientific research. Yet, the latter have important interest and value to this generation of scientists.

Faraday, born a blacksmith's son, had no silver spoon in his mouth to pay his way to Oxford or Cambridge Universities. Instead, he carried newspapers while a boy, and then learned the trade of bookbinding. We may gather that he disliked bookbinding, but appreciated the opportunity it afforded him to read scientific books. While still a young man, he began the practice of keen observation and the careful recording of what he observed. His intellectual curiosity

(*Continued on next page*)

attracted him to Sir Humphrey Davy's lectures which in turn brought him to a decision that cost England a bookbinder but gained for the world a great scientist.

While working with Davy at the Royal Institution, he met once a week with a group of friends of humble station in life having as their objective "mutual instruction." This consisted of reading to each other, then criticizing, correcting, and improving pronunciation and construction of language. Faraday, referring to this period in his life, wrote: "The discipline was very sturdy and the remarks very plain and open, and the results most valuable." Of the worth of this self-education and personal discipline we can have little doubt judging by the clarity with which he wrote, and the quantity and degree of detail he exacted of himself in almost the whole breadth of the physical sciences including electrochemistry, electricity, magnetism, optics, chemistry, and metallurgy. His "Experimental Researches" are a crowning glory to a self-regulated educational program that far exceeded in results anything that might have been expected of him through other channels.

His maturity of thought extended to subjects outside of science and included a philosophy of life that gave great depth of focus to his purpose in the laboratory. He said in a lecture on "Inertia of the Mind" in 1817, when he was but 26 years of age, that "Industry is the natural state of man, and perfection of his nature is dependent on it; the progression which distinguishes him from everything else in the material world is maintained by it alone.—An animal is born, grows up, and at last gives signs even of intelligence; but he dies without having improved his species; and it is *man alone* who leaves a memento behind him—; who surpasses his predecessors, exhalts his present generation, and supports those that follow him—If he be not active, not in a state of improvement, what better is he than the brutes?"

A Review of The Electrochemistry of Stressed Metals*

M. T. Simnad†

Introduction

It has long been known that plastic deformation affects the properties of metals and alloys, but it is only during the past twenty years or so that systematic and reliable studies have been made of the chemical and physical manifestations of internal stresses in metals. Increased interest is now being shown in the subject, especially in England where the recent Symposium on Internal Stresses attracted widespread attention (1). There is still, however, great controversy over the interpretation of the results obtained and much remains to be found out. Its important bearing on the electrochemistry of metals needs to be stressed, and the purpose of this paper is to furnish a critical survey of published work on the subject.

The Origin and Nature of Internal Stresses

Internal stresses are those existing in bodies upon which no external forces are acting, and have been classified into the following groups (2):

1. *Body (or Heyn) stresses*, arising from microscopic nonuniformities of mechanical, thermal, or chemical influences. These may be due to deformations such as in wire drawing, where the center is in compression and the surface is in tension; to nonuniform heating and cooling, as in castings; and to chemical nonuniformities, such as those arising during nitriding.

2. *Textural (or tessellated (3)) stresses*, due to microscopic inhomogeneities produced by:

(*a*) Gliding or kinking (4), which give rise to very high stresses around the lines where atomic misfit takes place. These dislocations (5) accumulate during plastic deformation, resulting in strain hardening. But, as Mehl (6) has pointed out, the hardening resulting from cold work still presents a theoretical problem of considerable magnitude.

(*b*) Varying orientation of grains in polycrystalline metals giving rise to textural stresses owing to the anisotropy of neighboring grains (7).

(*c*) Grain-boundary stresses, arising from difficulty of grains to adapt themselves to deformation of neighboring grains. In a recent paper, Boas and Hargreaves (8) have shown that the variation of plastic deformation in aluminum crystals varied from grain to grain, and also within each grain the deformation near the grain boundary was greater or smaller than at the center according to whether the neighbor was more or less deformed.

(*d*) Martensitic transformations, associated with a type of structural stress due to the transformation of the lattice from an unstable to a more stable phase (9).

(*e*) Differences of thermal expansion (10), either in materials containing several constituents with different coefficients of thermal expansion, or in noncubic metals where the thermal expansion of the crystals is different in different directions.

(*f*) Precipitation of a new phase, producing shear stresses because of the difference in the lattice planes of the two phases (11), and the difference between the volume of the precipitated phase in the unstressed state and that of the hole it occupies in the matrix (12).

Latent Energy in Deformed Metals

The heat evolved during a certain deformation is less than the work done in producing the deformation. The difference is a measure of the energy absorbed by the metal and is responsible for the change in physical and chemical properties which are characteristic of stressed metals (13). It is unfortunate that the measurement of latent energy in worked metals has not received the attention which it merits, and the wide discrepancy between the values ascribed to it calls for a clarification of the problem.

The reported values of latent energy in deformed metals range between 0 and 70 per cent of the work done in deforming the metal (14), these figures being equivalent to between 0 and 15 calories per

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gram. Consequently, there is a corresponding divergence between the calculated values of the change in electrode potential resulting from cold work. The experimental methods employed consisted either in measuring the rise in temperature of the specimens during deformation, or in measuring the heat evolved during deformation by means of a calorimeter. Taylor and Quinney (15) found that very much more cold work can be done on a metal in torsion than in direct tension, but that as the total amount of cold work which has been done on a specimen increases, the proportion which is absorbed decreases. By using compression instead of torsion it was found possible to do even more cold work on the metal, and their tests showed that the compressive stress increased with increasing strain until the total applied cold work was equivalent to 15 calories per gram. No further rise in compressive stress occurred with further compression, and the fact that the absorption of latent energy and the increase in strength both ceased when the same amount of cold work had been applied suggested that the strength of pure metals depends only on the amount of cold work latent in them. On the other hand, Wood (16) compared the lattice dimensions of cold-worked and annealed copper with the aid of precision x-ray methods, and interpreted the measured expansion of the lattice in terms of the equivalent heat energy required to produce a similar state. It is highly significant that the latent energy was found to be localized at certain portions of the metal and was not evenly distributed. In a given volume of cold-worked metal, about 15/16ths corresponded to a homogeneous deformation which was equivalent to a temperature rise of 17°C, and 1/16th corresponded in some way to inhomogeneous deformation equivalent to temperature increase between 0° and 100°C. The result was an average of 1.7 calories/gram as latent energy, which agreed with the value obtained by Taylor and Quinney. The manifold implications of this phenomenon have not been adequately considered or followed up.

Wood (17) also measured by x-ray diffraction techniques the actual displacement of atoms from their normal position under stress, and of their recovery when the applied stress is removed. As the yield point was exceeded some distortion took place which resulted in a permanent expansion of the lattice. This expansion was retained by the lattice spacing after removal of the load and represented an absorption of energy, or latent energy due to cold work. In this connection it is pertinent to quote also the x-ray study of Greenough (18), who drew attention to the fact that the residual lattice strain found by x-ray reflection is not the mean of the strains of all the grains, which is zero, but a mean of the strains of the grains with particular orientations. In a polycrystalline aggregate a complicated stress system will arise upon removal of the load—grains of high yield tension will remain in tension, and those of low yield tension will be in compression; this plastic anisotropy thus leads to a localization of the latent energy.

The extensive study of the subject by Maier (19) appears to have escaped notice owing to the misleading title of his paper. He observed the density changes in cold-worked copper and iron, and used them as a basis for attempting to calculate the changes in energy content of the metals from fundamental thermodynamic equations. He arrived at the conclusion that the directly determined values for stored energy are inconsistent with the calculated values. Some of his assumptions are, however, questionable, such as his application of thermodynamic equations to permanent changes of volume, and the supposition that the stresses are uniformly distributed.

More recently, Goranson (20) and Swainger (21) have correlated the phenomena of deformation, creep, and rupture from a study of internal energy stored in the lattice of a metal as a result of deformation. Freudenthal and Reiner (22) have put forward a law of hardening which correlates the recoverable strain work with the total work of deformation in a series of exponential functions, the number of which corresponds to the number of sizes of crystal grains present in the annealed state.

Electrochemical Manifestations of Internal Stress

Influence of Stress on Electrode Potential and Corrosion Rate

The latent energy in a deformed metal should be manifest as a change in the electrode potential of the metal and in its resistance to corrosion. Much research has been directed to the effect of deformation on electrode potential (23), but the results have been contradictory since none of the measurements were of the actual reversible potential, and the methods of surface preparation were unsatisfactory. The corrosion potential of a metal does not usually bear a simple relation to its unpolarized potential, and most of the controversy on the subject may be traced to neglect of this factor. In neutral solutions it is difficult to distinguish between the effect of the oxide film and that of the underlying metal*, while in acid solutions the effect of polarization becomes the predominant factor.

The earliest mention of the increased rate of solution following cold work is made by Osmond and Werth (24), and has been confirmed by many others (25). The work of Friend (26) demonstrated the influence of the nature of the solution on the corrosion of a metal. His results showed that in aerated salt solutions the rate of solution is not increased by cold work, since here attack is largely controlled by the

* According to Harwood (23), the work of Druet and Jacquet (23) on the electrode potential of film-free aluminum in neutral solutions does show an appreciable lowering of the potential by cold work. The author now agrees with this view.

oxygen supply. Skapski and Chyzewski (27) confirmed this result and also found that the pH of a solution has to be below 4 before the effect of cold work becomes appreciable. Whiteley and Hallimond (28) made the interesting discovery that nitric acid acting on strained iron produced nitrogen compounds in proportions differing from those obtained with unstrained iron. They ascribed this effect wholly to the increase in latent energy produced by straining the metal, since grain size did not affect the results obtained.

The experimental work at Cambridge and elsewhere (29) has indicated that the corrosion of metals in aqueous solutions is largely an

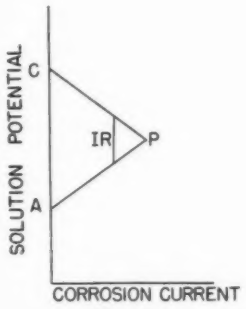

FIG. 1

electrochemical process. The graphical method introduced by Evans (30) has proved useful and convenient for expressing the manner in which various factors may be expected to determine the corrosion rate. When current flows between the anodes and cathodes on the corroding metal, both potentials, A and C (Fig. 1), are shifted so as to approach one another. The corrosion velocity developed corresponds, in the sense of Faraday's law, to a current of that value I which will produce an intercept between the anodic and cathodic polarization curves equal to IR, where R is the resistance of the circuit. In acid solution, where the resistance is low and the anodes and cathodes are generally close together, it may be assumed that the intersection point P does represent the current flowing. The corrosion velocity will then be I/F, where F is Faraday's number. If the anodic and cathodic curves (Fig. 2) are AP and CP in the absence of stress, the corrosion current will be the abscissa of P. Now if the effect of stress is to shift the anodic curve down to A_1, the current will be increased to P_1, while if the effect is to diminish anodic polarization the anodic curve will be

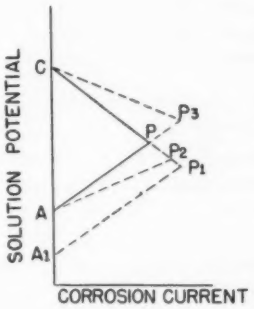

FIG. 2

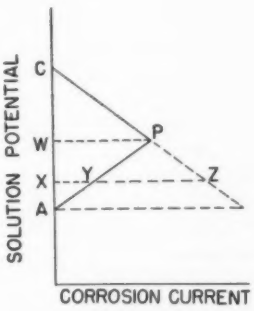

FIG. 3

less steep (AP_2) and the corresponding current will be the abscissa of P_2. On the other hand, a reduction in the cathodic polarization will give a new cathodic current equal to the abscissa of P_3.

This graphical method was elaborated by Mears and Brown (31), and by Hoar (32), in their theoretical treatment of the mechanism of cathodic protection. If the applied cathodic current is represented by the length YZ (Fig. 3), the corrosion current will be reduced from the value WP to XY. A current sufficiently strong to prevent corrosion altogether will depress the potential to the value of the unpolarized anode A. Thus the measurement of potentials and corrosion rates with various applied currents should give a quantitative measure of the effect of deformation on corrosion rate. Simnad and Evans (33) have made such measurements on iron and steel in acid solution and their results indicate that the unpolarized potential of cold-worked iron and steel is anodic in relation to the same metal in the annealed condition. The same difference was observed in experiments where a cathodic current (either greater or smaller than the protective value) was applied; at any current density, the potential of the annealed specimens was about 25 millivolts nobler than that of the cold-rolled material. The cathodic polarization curves also showed a break at the point where the applied current reached the protective value.

It is of interest to correlate the change in free energy resulting from cold work with the corresponding change in potential found experimentally. The thermodynamic considerations in the corrosion of metals have been discussed by Warner (34), Sweeney (35), and Pourbaix (36). As Warner points out, if the process occurs by an electrochemical mechanism, the maximum (reversible) potential of the corrosion couple can be calculated, and this potential can be considered the driving force of the corrosion process. On the other hand, if the process is considered to be spontaneous, the conditions for the steady state can be stated by setting the energy decrease in the process equal to the sum of the energies dissipated in the various parts of the electrochemical system. The difference between the potential of the anode and the cathode at zero current represents the reversible or driving force of the corrosion couple. The free energy change is related to the reaction potential by the equation (37):

$$\Delta G = -nFE$$

where n is the valence, F the Fara-

day, and E the single electrode potential. For iron, a change of 25 millivolts in potential, resulting from cold work, corresponds to an increase in free energy equal to approximately 10 calories per gram. This appears to be of the correct order of magnitude as compared with the reported values of latent energy in deformed metals, especially when allowance is made for the localization of latent energy in the metal.

It may be possible to calculate the change in heat content (ΔH), and in entropy, of deformed metals by measuring the temperature coefficient of the emf and applying the Gibbs-Helmholtz equation in its form:

$$\Delta G = \Delta H + T\left(\frac{\partial(\Delta G)}{\partial T}\right)_P$$

and since $\Delta G = -nFE$, it follows that

$$\Delta H = -nF\left(E - T\left(\frac{\partial E}{\partial T}\right)_P\right)$$

Work is in progress by the author to apply this method to measure the amount of latent energy present in deformed metals, since it is usually far more accurate than the calorimetric methods.

No work appears to have been done on the influence of cold work on overvoltage. It is difficult to predict the effect of cold work in view of the fundamental differences between the various theories of overvoltage. Work is in progress by Moore and the author on experiments to compare the overpotentials of annealed and deformed metals (126).

The relations defining the condition of equilibrium for solids in contact with liquids, having regard to all possible states of strain of the solids, were developed by J. Willard Gibbs (38), who considered the process reversible. It is well known to crystallographers that a loaded crystal is thermodynamically different from the unloaded crystal: the loaded crystal on growing orients the atoms which come within range of its component atoms in such a way that the newly deposited layers are deposited in a state corresponding to that of the loaded crystal, and there is no line of demarcation in strain between the original crystal and the freshly deposited layers (39). Riecke's (40) principle, based on his theoretical analysis, indicates that a crystal under uniform stress is not in equilibrium with a solution that was saturated before the stress was applied; it will begin to dissolve. If another crystal is present in the solution, not stressed, it will grow as the stressed crystal dissolves.

Effect of Surface Preparation on Corrosion

The important effect of surface condition is well brought out in the following experiment (41). Steel abraded with emery, annealed in vacuo, and again abraded is attacked in acid solution 30 per cent more quickly than steel on which the final abrasion is omitted. A striking practical application of the increased reactivity of a freshly deformed surface is in the preparation of organometallic compounds by Shaw (42), who was able to prepare these difficult compounds by the metal-cutting process. He observed that in metal-cutting the cutting liquid is subjected to pressures of the order of the hardness of the metal cut, high local temperatures limited only by the melting point of the material, and nascent highly stressed metal surfaces. This combination of conditions was found to promote the difficult chemical reactions.

Surface stress appears to decrease the corrosion resistance of even the purest metals. Thus Lambert (43) found that very highly purified iron, which would not corrode in pure water even after several months, soon corroded if pressed with an agate mortar. Similarly, the pure iron which did not react with copper sulfate solution, at once did so if pressed with a quartz rod when in the solution. Evans attributes this to a breakdown of the oxide film on the metal (44). The influence of oxide films on the resistance of a metal to corrosion has been emphasized by Evans (45) by the following experiment: finely abraded copper bent locally immediately after grinding and placed in silver nitrate solution showed general blackening all over. Similar copper abraded, kept in a dessicator nine days before being bent, and then placed in silver nitrate solution, showed marked deposition of silver all around the bend and practically none elsewhere. The same copper, bent and then kept nine days in a dessicator, showed no deposition at the bend in the silver nitrate solution.

The author recently demonstrated the influence of bending on the passivity of iron in nitric acid (46). If iron is dipped in strong nitric acid, it remains passive when subsequently placed in dilute nitric acid. If, however, the metal is bent just before being placed in the dilute nitric acid, it is violently attacked at the bend, where the stresses are greatest and the protective film is broken.

By transfer of oxide films from metals to a vaseline basis, Evans (47) has shown clearly that stresses exist in the oxides during attachment to the metals. Thus thick films showed wrinkles, suggesting uniform stress due to misfit between the volumes occupied by oxide and metal, while the thinner films curled into rolls, suggesting a stress gradient, probably inherited from surface stresses in the metal. The electron diffraction method is well suited to the study of such surface structures and oxides, and has been used to examine them in detail (48), but there has been no quantitative measurement or calculation of the magnitude of the stresses present in oxide films.

Recent studies, using precision x-ray methods, have shown that the distorted layer produced by mechanical polishing may extend an appreciable distance below the metal surface (49). Vacher (50) abraded annealed specimens of steel, copper, and aluminum and found that the back-reflection patterns of the specimens showed a progressive increase in the degree of diffuseness with thickness

in the range up to 25 microns in the steel, 42 microns in the copper, and 95 microns in the aluminum. A comparison of these patterns with others indicated that the cold-worked layers produced by certain fine-abrasive treatments were thicker than those produced by certain coarse abrasives. In general, there appears to be a zone of small crystals without special orientation on the surface, below which the grains are larger and possess a tendency to a common orientation, after which one passes gradually into the unchanged metal. Mechanically polished crystals show enhanced hardness as the surface is approached (51), whereas on electropolished crystals the hardness is comparatively constant.

Mechanical polishing also alters the chemical composition of the oxide film on a metal. Vernon (52) discovered this effect during a study of the surface film on stainless steel. The surface film was stripped from 18–8 stainless steel and the metals present were determined by chemical analysis; the contents of the corresponding oxides were computed. The thickness of the film as measured increased with degree of polish (this was previously observed by Dobinski (53) in the course of electron-diffraction studies of oxide films). There was a marked enrichment of chromium in the film as compared with the underlying metal, and this enrichment of chromium also increased with degree of polish. Films from brightly polished specimens contained about 80 per cent chromium, the balance being mainly ferric oxide. No enrichment of nickel was observed. The use of chromic oxide as a final polishing agent did not appreciably affect the content of chromic oxide in the film. When alumina was used for the final polishing it appeared in the film and the concentration of chromic oxide was simultaneously reduced. Electrode potential measurements of specimens immersed in sodium chloride solution confirmed that polishing with alumina yielded a less passive surface than polishing with chromic oxide. It was concluded that the rate of oxidation under these conditions is controlled partly by the free energies of formation of the respective oxides, and probably to a greater extent by selective oxidation arising from the restriction of oxygen at the interface between the metal and the polishing material.

The influence of the preferred orientation produced by cold rolling should be distinguished from the effect which may be ascribed to the presence of internal stresses. Derge (54) has reviewed this aspect of the problem in a paper on the relation between crystal structure and corrosion. Tammann (55) had shown that copper crystals oxidize at different rates according to their orientations, while Glauner (56) found that the (111) face of copper dissolves about twice as fast as the (110) face in 0.3*N* acetic acid containing 0.1*N* hydrogen peroxide. The potentials of zinc single crystals were measured by Straumanis (57) and Anderson (58) at about the same time, but they interpreted the results differently. Straumanis claimed that there is no difference in potential between four artificially prepared planes of single crystals of zinc in neutral zinc sulfate solution; distortion of the surface made the potential less noble. It is significant, however, that the plane of etching did not develop parallel to the original plane when the surface of the crystal was etched strongly enough to show the structure of the crystal.

Anderson, in a classic paper, drew attention to the importance of correlating electrode potential measurements to a structure definitely describable in a crystallographic sense. This is especially desirable for correlating electromotive data with photoelectric and electron condensation measurements. Anderson found that the potential of the primary cleavage face (basal pinacoid) of zinc single crystals was identical to that of electrolytically deposited crystal conglomerates. His measurements of artificially prepared surfaces at different orientations, annealed and etched, seemed to indicate a qualitatively regular decrease of potential with increase of inclination to the primary cleavage plane. On the other hand, his results also indicated that the surface structures of the crystals which had attained the equilibrium potential were broken rather than regular, and it was clear that the equilibrium potential could not be assigned to the original crystal face, but only to the stepwise growth faces of the crystal. He, therefore, makes the cogent criticism of the measurements of Straumanis to the effect that these were for the equilibrium state and threw no light on the orientation-potential question. For such work it is essential to use single metal crystals with naturally developed faces, and to measure the initial potentials in order to estimate the effect of orientation. The same comment may be made on the more recent work of Walton (59), who attempted to correlate the potentials with orientations of single crystals of aluminum, and found little difference in potential between the various faces, although the (111) plane dissolved appreciably faster than the (001) plane.

Harker (60) made the very important contribution to the discussion of this paper, namely that the etched surfaces of single crystals consist of tiny peaks and valleys bounded by small facets all parallel to one of the important crystallographic planes. Hence the true surface areas differ from the apparent areas, but the free energy or the potential of any etched crystal face must be the same. The corrosion rate, however, varies with the true surface area and there is, therefore, no contradiction between the experimental facts.

The unusual technique used by Beeck, Smith, and Wheeler (61) for producing oriented and unoriented metal films on glass, by controlling the pressure of an inert gas during evaporation of the metals, may be applied with advantage for orientation-potential-stress measurements. Beeck, *et al.*, found that the enhanced

catalytic activity of certain oriented films was related to the relative atomic distances on the surface planes.* It would appear, therefore, that stress should further alter the activities of surfaces, since both the lattice constants and the free energy of the metal are changed by stress. Work is in progress in this laboratory by Ruder and Simnad to determine the rates of ion-exchange of cold-worked and annealed metals in solutions containing their radioactive ions (62), and their relative activities.

Stress Corrosion of Nonferrous Metals

Susceptibility to stress-corrosion cracking is generally associated with the presence of a continuous zone within the metal that is anodic to the rest of the metal. The formation of these susceptible zones by precipitation from solid solution has been exhaustively surveyed by Geissler (63). He attributes aging in such alloys to the precipitation process which embraces the initial formation of a transition lattice, a subsequent formation of the equilibrium phase, recrystallization or recovery of the matrix, and the superimposed overall change in the composition of the matrix solid solution. These reactions are accelerated at grain boundaries and at plastically strained areas, such as slip planes. It is characteristic of stress corrosion that the corrosive solutions which produce cracking are specific to each metal. As Allen (64) has pointed out, this association must be explained by any satisfactory theory of stress corrosion.

Mears, Brown, and Dix (65) have put forward a generalized theory of stress corrosion of alloys. They state that in order for corrosion to occur: (*a*) there must exist in the alloy a susceptibility to selective corrosion along more or less continuous paths, as for instance at grain boundaries, and (*b*) there must exist a condition of high stress acting in a direction tending to pull the metal apart along these continuous paths. They point out that the path of the stress-corrosion attack can be either along grain boundaries or through the grains (the same metal may stress-corrosion crack in an intercrystalline manner in some environments and transcrystalline crack in other environments). The corrosion, in most cases, occurs by an electrochemical mechanism, the localized path being the anode and the surrounding area the cathode, but the anodic and cathodic characteristics vary with the nature of the corroding solution. Once the crevices or localized paths are corroded, the stress further opens the crevices. Stress-corrosion attack can be prevented by cathodic protection, except in such cases as the attack of mercuric chloride on brass, since this is a case of rapid amalgamation at grain boundaries.

Dix (66) has suggested that ingenious investigators can find solutions which will stress-corrosion crack any known metal or alloy, but it seems a moot point whether this applies to really pure metals. The use of a chemical reagent for the detection of internal stresses was first described by Roberts-Austen (67), who used ferric chloride on 13 carat gold. This solution has recently been used for the same purpose on silver-platinum alloys (68).

The season cracking of stressed copper alloys has been known for a long time (69), but there is still no adequate explanation of this phenomenon even though the factors involved are well recognized. According to Cook (70), all available evidence indicates that pure copper can be regarded as free from liability to stress-corrosion cracking, and the possibility of failure in brass is limited to alloys containing less than 80 per cent copper. Silicon has a definite beneficial effect on brass, whereas alloys of copper with aluminum, nickel, tin, and silicon are all susceptible (71). The rate of cracking increases with grain size and inversely with degree and direction of cold work. It is not eliminated in single crystals of brass, which shows that grain boundaries are not the only susceptible areas. In the mercurous nitrate test for season cracking there is a threshold stress below which no cracking takes place. Compressive stresses may actually increase the resistance of a metal. Thus, Albin (72) found that surface hammering of a copper distillation column (for acetic acid) greatly increased its life (probably the copper was not pure).

Mprica (73) found an increase in the potential of brass caused by the application of tensile stress. He gave the following explanation of stress-corrosion cracking in brass: at the bottom of small furrows in the roughened surface the stress is greater than at the ridges immediately adjacent; a galvanic couple is formed, and only the bottom of the furrows is corroded, forming cracks. These fissures appear to favor the β-phase in the brass and to avoid the α-phase in a brass containing both. Evans (74) points out that in acid solutions penetration along grain boundaries would be opposed by a back emf due to the accumulation of copper ions in the crevices, whereas ammonia will prevent any such accumulation, locking up the copper as stable complexes, so that an operative emf remains. A combination of these two factors may explain to some extent the phenomenon of season cracking in brass, but does not explain why it does not occur in pure copper.

Zinc has been found to be influenced by the presence of internal stresses; Brownsdon (75) cites the case of zinc tubes used in dry batteries which perforated more rapidly if used in the cold-worked condition than if annealed.

The corrosion resistance of magnesium alloys has been extensively

* In their recent papers on catalysis, Cooper, *et al.* (61) ascribe the catalytic activity of transition metals to the presence of unpaired d-electrons in the electronic d-band of the metals. This theory is akin to Uhlig's electron-configuration theory of passivity, and has to be considered seriously in view of their experimental evidence in support of it.

studied in recent years (76): the effect of heat treatment varies with heat treating temperature, impurity content, rate of cooling, and alloying elements. Hansen (77) showed that the stress-corrosion cracking of magnesium-base alloys containing aluminum is transcrystalline, whereas in aluminum-base alloys containing 9 per cent magnesium the failure is intercrystalline.

Dix (78) put forward the theory that in aluminum-copper alloys the precipitation of a copper-rich constituent leaves the remaining part of the intergranular material denuded of copper and, therefore, anodic to the main mass of the crystal. Thus, for an alloy of 4 per cent copper content, the potential is −0.69 volt when the copper is in solid solution, compared to −0.84 volt for pure aluminum. Precipitation of $CuAl_2$, whose potential is −0.53 volt, occurs more rapidly at the grain boundaries than within the grains, and the depleted zone becomes anodic to the grain centers (79). A maximum difference of 30 millivolts between the grain boundaries and the grain centers has been found after about eight hours aging at 375°F, while after 32 hours there was no difference in potential since precipitation also had taken place completely within the grains. Mears, Brown, and Dix (79) also concur with Whitwham (80) in recognizing the important role of the oxide films present on metals upon their resistance to stress-corrosion cracking. If the stress is not sufficient to produce cracks in the film, stress-corrosion cracking may not occur, and vice versa.

The magnitude of the stresses arising in the separation of a new phase have been calculated by Zakharova and Lashko (81), who take into account the stresses arising in diffusion processes due to the concentration gradient present around the nucleus of the new phase. In the case of the decomposition of a 5 per cent copper-aluminum alloy, the residual stress in the immediate neighborhood of the precipitate is estimated as 34 kg/sq mm, while at a distance equal to ten times the radius of the nucleus it falls to 0.3 kg/sq mm; the corresponding tangential stresses are estimated equal to 38 and 0.00005 kg/sq mm, respectively. Radavich and Smoluchowski (82) attempted to measure the influence of hydrostatic pressure on diffusion in the copper-aluminum system. A decrease in the diffusion rate was found corresponding to about 30 per cent of the diffusion coefficient at a load of 7000 kg/sq cm. Hashigashi (83) claims that cold work accelerates the diffusion of aluminum in copper, and also states that the activation energy of recrystallization of cold-worked copper tends to that of its self-diffusion activation energy.

Recent work has emphasized the importance of the purity of the metals used in such experiments. A case in point is the unusual phenomenon of thermal hardening, which was first observed by Orowan (84) in zinc crystals. When a zinc crystal was annealed after a small plastic extension, it remained elastic up to a yield stress much higher than the previously determined normal value. The crystal would then suddenly yield and continue to extend plastically at the normal lower yield stress, whereas a freshly strained crystal began to flow at a lower yield stress. This phenomenon has also been observed in cadmium (85) crystals, and in aluminum bronze (86) containing 5 to 9 per cent aluminum rolled and then annealed at 300°C. However, Cottrell (87) has discovered the important fact that if the crystals are melted and annealed in pure argon atmosphere, they give no sign of this thermal hardening effect. He ascribes the phenomenon, as in the case of the yield phenomenon in iron containing carbon or nitrogen, to the migration of foreign atoms to dislocations in the metal, where they relieve the stresses by altering locally the equilibrium lattice constants. A large force is then required to tear a dislocation from its cloud of solute atoms, and when a dislocation has in this way been freed, it can migrate rapidly through the lattice under a smaller force.

The dislocation theory has been applied to explain the effect of precipitation on physical properties (88). Plastic deformation of metals occurs principally by the motion of linear imperfections of the lattice across the glide planes of the crystals. When a dislocation moves completely across a glide plane from one side to the other, the material on one side of the glide plane is displaced relative to the material on the other side. The dislocation as a whole can move only if the external stress is large enough to overcome the internal stress over the whole length of the dislocation.

Gayler (89) emphasizes the importance of the presence of these submicroscopic and microscopic stresses in relation to the behavior under stress corrosion of alloys which age-harden, since cold work accelerates age-hardening. She quotes the results of Grogan and Pleasance (90) who found that aluminum −4 per cent copper alloy quenched and aged at room temperature is less susceptible to stress corrosion than when aged at a higher temperature; in the former state sub-microscopic stresses are developing, and in the latter, microscopic stresses: in both cases, however, these internal stresses govern the direction of development of the cracks and accelerate their formation under applied external stress.

Stress Corrosion of Ferrous Metals

This field has been admirably surveyed by Uhlig (91), to whose article reference may be made for a more detailed account of the subject. The best known case of stress-corrosion cracking of steel is the phenomenon of caustic embrittlement, which takes place in alkaline solutions in the presence of impurities and the failure is usually intergranular (92). In certain other solutions, however, the stress-corrosion cracking is transgranular, e.g., in hot calcium-ammonium nitrate (93) or in aqueous solutions of hydrogen cyanide (94). On the other hand, a solution of 46 per cent magnesium chloride at

125°C, which causes stress-corrosion cracking of stainless steels, is ineffective against mild steel (95). The susceptibility of mild steel to stress-corrosion cracking in alkalis and nitrates has been ascribed to the presence of nitrogen.

The early work of Koster (96) showed that nitrogen is more soluble in iron at high than at low temperatures. Its separation from supersaturated solid solution at room temperature is very slow, but is accelerated by deformation. The separation of nitrogen results in a decreased resistance to chemical attack. Schottky and Hiltenkamp (97) claimed that severe local friction of steel parts results in surface nitrogenization of the steel, which causes embrittlement of the cold-worked surface and leads to the formation of fatigue cracks. The internal stresses produced by friction have been clearly demonstrated recently by Bowden and Moore (98), who conclude that adhesion and shearing takes place between sliding metal surfaces resulting in distorted layers extending as much as 300 microns beneath the surface.

Waber and McDonald (99), in a lengthy paper, have put forward the theory that the stress-corrosion cracking of mild steel in nitrate solutions depends upon the stress-accelerated age-hardening, which is correlated with the free-nitrogen factor. They consider the rate and direction of the growth of the cracks to depend upon the localized electrochemical condition induced by the mechanical forces. After a minute crack has formed, the stresses at the apex of the crack, due to stress concentration, accelerate the precipitation of the supersaturated solid phase. Then the corroding solution dissolves the more anodic of the two product phases. The removal of nitrogen and carbon from steel eliminates both quench and strain aging and also susceptibility to cracking. Huddle (100) has raised the objection to this theory to the effect that a precipitated phase, nitride and/or carbide, should be cathodic to the ferrite on thermodynamic grounds. He considers the oxide film on the ferrite to be functioning as cathode, the precipitate in the grain boundary being attacked; the function of the stress is to promote the breakdown of the film. In addition, the strain energy at the apex of the pit will tend to shift the potential in an anodic direction.

Austenitic stainless steels become sensitive to attack along grain boundaries if heated in the range 500–900°C. If heated to higher temperatures, when all the carbon passes into solution, transgranular attack takes place in acid chloride solutions. The difference in the two cases is ascribed to the precipitation of carbide along the grain boundaries at the lower temperature range (101). The region near the grain boundaries thus becomes denuded of chromium and is more easily corroded.

The temperature at which susceptibility begins is lowered by cold work (102), and the carbide is precipitated on slip planes as well as at grain boundaries. Similarly, the upper temperature of this range is also lowered, since diffusion is more rapid in the cold-worked material, because the grains are smaller. With sufficient cold work, intergranular attack is largely avoided since the carbide is more uniformly distributed. McLean and Northcott (103), however, still repudiate the separation of a carbide at the grain boundaries. They suggest that there is merely a high concentration of solute atoms, such as carbon, at the grain boundary because of distorted lattice there; the concentration is considered to fall smoothly away from the boundary into the less distorted lattice. On the other hand, Mahla and Nielsen's (104) beautiful electron microscope photographs appear to leave little doubt regarding the presence of carbides at the grain boundaries. Birchenall and the author are using radioactive chromium in stainless steel to follow the mechanism of chromium depletion at the grain boundaries, as well as of passivity and oxidation in the presence of chromium (105).

Corrosion Fatigue

It is well known that the resistance of a metal to fatigue failure is reduced far more when subjected to the simultaneous action of corrosion and repeated stress, than by stressless corrosion followed by air fatigue. This phenomenon was first brought to notice during World War I, when the towing wires of the paravanes used for mine sweeping were found to fail after very short periods of service, despite the fact that they were subjected to loads far below their tensile strength. The explanation was that the vibration of the wires in sea water caused rapid pitting to take place; this inevitably reduced the strength of the wires in a very short time. Many of the premature failures met with in engineering practice have since been ascribed to corrosion fatigue, especially where there has been a tendency to reduce the factor of safety (106).

The first published account of corrosion fatigue was given by Haigh (107) in 1917. He observed that the superficial etching of brass with ammonia when carried out prior to testing under alternating stress did not appreciably affect the result, whereas the endurance was much reduced when the corrosive action of ammonia was operating during the test. Not much notice appears to have been taken of this experiment, and the subject remained buried for another nine years, until it was accidentally rediscovered by McAdam (108), who was engaged in testing the cooling effect of water on the fatigue resistance of steels. The resistance of the specimens to fatigue was greatly reduced by corrosion pitting caused by the water, and this led him to a lengthy study of corrosion fatigue. His results proved conclusively that the damage caused by simultaneous corrosion and cyclic stress is far more potent than the damage caused in the same time by

stressless corrosion. Also, the greater the stress, cycle frequency, and time, the greater is the difference between the resultant damage and the corresponding loss in strength caused by stressless corrosion.

Gough and Sopwith (109), during a microscopic and x-ray examination of the behavior of single crystals of aluminum under alternating torsional stresses while immersed in water, observed: (*a*) a general pitting attack, consisting of a large number of small corrosion pits, (*b*) local attack, shown by the formation of larger pits, and (*c*) preferential attack at the site of slip bands, leading to fracture. Failure always took place by the formation of pits and cracks in areas undergoing heavy plastic deformation.

Gerard and Sutton (110), studying the corrosion fatigue of duralumin, verified the improvement produced by zinc plating which confers cathodic protection. Similarly, steel zinc plating or sprayed zinc coating give far greater protection than tin coatings (111). The protective effect of chromates was demonstrated by Speller (112) and Fink (113). This inhibitive action of chromates was studied quantitatively by Gould and Evans (114), who showed that the electrode potential suddenly underwent a change when a breakdown of the protective film formed by the chromate occurred. Both film-life and time to fracture diminished with increase of stress range or of chloride concentration, while both were lengthened by an increase in chromate concentration.

The electrochemistry of corrosion fatigue was studied by Simnad and Evans (115) in an attempt to elucidate the mechanism of the process. It was followed in both acid and salt solutions by: (*a*) measurements of the residual air-fatigue life and microstructure in experiments interrupted at different stages, (*b*) determining the influence of stress range on corrosion velocity, and (*c*) measuring the electrode potentials and corrosion velocities with applied cathodic currents. The two-stage tests, in which the flow of corrosive solution was stopped after a definite period and the specimens subjected to the same range of alternating stresses in air, indicated that at each stress range a definite period of corrosion fatigue can be tolerated by the specimens with safety. If the corrosive solution is applied for a period longer than this "incubation stage," the total life is greatly reduced. There appeared to be a minimum total life corresponding to a definite corrosion-fatigue period. The effect of alternating stresses on the rates of corrosion in acid differed markedly from the corresponding effect in salt solutions. In the latter, the corrosion velocity increased with stress range from the start but was constant with time. In acid, on the other hand, the stress range hardly affected the initial corrosion velocity, showing that within the elastic range alternating stresses have little influence on the corrosion velocity; but shortly before fracture the corrosion rate suddenly increased markedly, together with a rapid fall in the electrode potential. This reflected the fact that mechanical damage greatly enhances corrosion velocity. The application of cathodic currents diminished the rates of corrosion: above a certain value corrosion became undetectable and the life became extremely long in neutral salt solutions. The current needed for complete protection increased with stress range, and the value of the potential corresponding to the protective current decreased to a more anodic value with increase in the applied stress.

Applying the graphical methods of representing corrosion phenomena to the results obtained, the authors were led to the view that three factors operate in causing alternating stresses to enhance the rate of corrosion and the rate of mechanical damage. These are: (*a*) diminution of cathodic and anodic polarization, (*b*) decrease in the resistance of the paths joining the anodes and cathodes, and (*c*) a bodily shift of the anodic polarization curve in a base metal direction caused by distortion of the metal lattice.

Internal Stresses in Electrodeposited Metals

Most normally electrodeposited metals contain internal stresses, and the subject has recently been reviewed by Hothersall (116), who points out that much more data are needed for correlating crystal structure and stress in electrodeposits, and on the changes occurring after deposition, before a comprehensive explanation of the phenomenon can be attempted. He also suggests that a knowledge of the causes of stress in deposits may almost be said to be essential to a better understanding of the mechanism of electrodeposition.

A summary of published information has been compiled by Hothersall (116). Conditions giving low cathode efficiency were found to give highly stressed deposits, and vice versa. The magnitude and also sometimes the direction of stress varies with the conditions of deposition. Of special interest is the increase in the compressive stress in electrodeposited zinc on standing dry after the deposition. Cochran (117) electrodeposited nickel on copper and copper on nickel and examined the electron-diffraction spectrum at different thicknesses of deposit. The first few atom layers of the deposit were found to have the atomic spacing of the basis metal, and this introduced stresses at the junction of the two metals. A similar situation has been found to exist at the junction of a metal and its oxide by Mehl and McCandless (118).

The electron-diffraction studies of Finch and Quarrell (119) are especially noteworthy. They discovered that a distorted polished surface has the remarkable property, not shared by the corresponding crystalline surface, of dissolving metals deposited thereon. Thus, at room temperature, zinc crystals dissolved rapidly in polished copper and somewhat less readily in polished mild steel surfaces, but were insoluble in

either of these surfaces after the distorted layer became saturated, whereupon further deposited layers retained their crystal structure indefinitely. Similar effects were observed with zinc, tin, lead, and silver flashed onto copper, mild steel, lead, gold, and zinc surfaces; and cadmium and lithium films condensed on a polished copper layer. On electrodepositing zinc on copper, 30 seconds' electrodeposition at 0.1 amp/sq dm was sufficient to form a permanent crystalline zinc layer on crystalline copper, whereas 3 minutes were necessary if polished copper served as basis metal. They point out that in addition to exerting orientating, pseudomorphic, and solvent effects, an active substrate may also affect the crystal size in electrodeposits. Thus, chromium deposited on copper gave smaller crystals and correspondingly broader ringed patterns than on nickel, iron, tin, or bismuth, although the experimental conditions were otherwise unchanged. The substrate also appeared to exert a profound effect upon the occlusion of gas by an electrodeposited film, as was shown by the various extra ring and band series in the electron-diffraction patterns. Mehl (120) cites that upon copper plating a deformed single crystal of brass, the twin bands present in the brass were inherited by the plated copper.

Several attempts have been made to use x-rays for determining the stress in electrodeposited metals, but complications arise from the very fine grain size of electrodeposits and by the differences in grain size and orientation which may exist between deposits of the same metal prepared by different methods. Mahla's (121) x-ray studies of copper deposits showed that at low temperatures the temperature is a greater factor than the current density in determining stress, while at high temperatures the current density was the principal factor. Hume-Rothery and Wyllie (122) applied x-rays to the examination of the structure of electrodeposited chromium. At any given current density the residual (tensile) stress increased with the temperature of deposition, reaching values as high as 27.5 tons/sq in. This increase continued until the temperature was reached at which particles of preferred orientation first made their appearance. With further rise of temperature, the residual stress fell until it was practically zero at the temperature at which the brightest deposits were formed, and then rose again at higher temperatures. The deposits of completely preferred orientation had the greatest hardness, and the temperature-hardness curves at different current densities could be superposed by shifting of the temperature scale.

Similarly, the work of Goldschmidt (123) verified the important influence of the base metal on the properties of chromium plate. He postulated the theory that nascent hydrogen goes into the steel substrate and pries up the lattice spacing of the steel base, and then the chromium, which needs a larger lattice on which to settle down, is compressed and produces an interfacial zone of high stress. He considered a good type of chromium deposit to be the result of strains caused by a metastable linkage with the expanded base matrix. Annealing gradually expels the hydrogen, relieving the strains and removing the lattice linkage effect, until the structure of the good sample becomes similar to that of the poor one. In poor quality chromium plate, the iron and chromium lattices are entirely separate to begin with and relatively unstrained. Preferred orientation in the chromium layer is pronounced in all cases, even when the steel base shows completely random orientation.

More recently, Brenner, Burkheed, and Jennings (124) have made a detailed x-ray study of the physical properties of electrodeposited chromium. In common with others, they were unable to detect microscopically any grain structure of chromium as deposited, but obtained well-defined grains after annealing in vacuo at 1400°C. They do not, however, believe that crystal orientation is primarily responsible for the hardness or stress in deposited metals. They contend that the oxide content of the deposits has a far greater influence on the physical properties than crystal orientation. The content of hydrogen and oxygen in the deposits was found to increase with current efficiency, and spalling resulted when a high internal pressure was generated by the hydrogen.

The effect of occluded hydrogen in metals and the stresses produced by it have been extensively studied, and there has been a considerable amount of writing on the subject. Smith (125) has surveyed the published work in a monograph which contains over 1400 references to the literature. The presence of internal stresses has been reported to increase the amount of hydrogen which could be introduced into a metal, but the rate of diffusion of hydrogen decreases with cold work.

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MANUSCRIPTS FOR SPRING MEETING

Manuscripts are now being received for the Ninety-Seventh Meeting of the Society, to be held at the Statler Hotel in Cleveland, Ohio, April 19, 20, 21, and 22, 1950. To be considered for this meeting, *triplicate copies* of manuscripts or abstracts must be received by the Editor of the Journal, 235 West 102nd Street, New York 25, N. Y., *not later than* February 15, 1950.

Current Affairs

Plan Intensive Program at Cleveland

Electrochemists attending the convention in Cleveland April 18th, 19th, 20th, 21st, and 22nd will find an interesting program of technical discussions, relaxing entertainment, and informative plant trips. Plans well under way indicate that the convention will be a "must" item for electrochemists with a wide variety of interests. Symposia will be presented covering the fields of Theoretical Electrochemistry, Rare Metals, Instrumentation, Electrothermics, Luminescence, Industrial Electrolytics, and Electric Insulation. From the number of papers under consideration, it appears that several sessions will require concurrent presentation of reports.

The Hotel Statler, located in the heart of the theater and shopping district, will be headquarters and most, if not all, of the meetings will be held on the Ballroom floor, thus allowing easy attendance at all sessions. Some 250 rooms, including suites, twin, double, and single bedrooms are being reserved for those who will attend the convention. Reservation cards will be forwarded from New York and should be sent promptly to the Hotel Statler to assure proper reservations.

Cleveland's Hotel Statler is an outstanding example in a long list of nationally famous Statlers, and was selected, after a careful study by the local committee, headed by Leon R. Westbrook, not only because of its excellent meeting facilities, but also for its service, guest accomodations, and convenience to many points of interest in Cleveland. N. M. Winslow is heading the Hotel Committee.

Banquet Scheduled for Thursday

Former President William G. Harvey will serve as toastmaster for the Annual Banquet which, in line with Society tradition, will be held Thursday evening. Annual business meeting will follow the luncheon Thursday noon. An informal evening of fellowship and sociability is tentatively planned for Friday evening.

LEON R. WESTBROOK
General Chairman

Plan for Ladies' Program

Although plans for the ladies have not been completed, tours and luncheons are in the offing with ample time assured to visit the shopping districts, museums, movies, and other places for which Cleveland is noted. Mrs. C. C. Rose and her committee have promised an interesting time for all ladies in attendance. It is expected that plans will be completed in time to be announced in the March issue of the JOURNAL.

Plant Trips Scheduled

Visiting electrochemists will do well to include in their program the trips to the NACA Lewis Flight Propulsion Laboratory and the B. F. Goodrich Research Center, scheduled for Thursday and Friday afternoons, respectively, by R. C. Hienton and his committee. The NACA laboratory, which is adjacent to the modern Cleveland Municipal Airport, will prove a revelation to those not acquainted with activities of this type. The Goodrich laboratory likewise will prove a model of convenience and adaptability.

Members of the Cleveland Section have visited both laboratories recently and will vouch for their interest. More details about these laboratories are given below.

Cleveland, The City

Cleveland is not only meetings, shopping districts, and laboratories. It is a live, thriving metropolis—the home of a wide variety of civic, cultural, and technical interests. Founded in 1796 by Moses Cleaveland at the mouth of the Cuyahoga River as it flows into Lake Erie, the city has grown with the development of industrial America. Serving as a meeting point for Mesabi iron ore, Pennsylvania coal, and Ohio limestone, Cleveland has become one of the leading centers for iron and steel production and fabrication. It has attracted related industries to give the Greater Cleveland metropolitan area a population approaching a million and a half. Nationality

N. M. WINSLOW
Chairman, Hotel Reservations

groups, integrated as good Americans and good citizens of Cleveland, yet maintain their Old World traditions and provide many cultural and family ties. Scotsmen, Welshmen, Poles, Bohemians, Italians, Hungarians, and Germans are among the peoples represented by large segments of the Cleveland population.

Cleveland Is Diversified

Workers—skilled, unskilled, professional—have found diversified and stable employment in Cleveland,—in the steel, paint, electrical, rubber, and chemical fields, to name only a few of the many local industries. Cleveland is the home of two pioneer chemical companies well known to electrochemists, Grasseli (now a division of Du Pont) and Harshaw. Cleveland is the home of General Electric's famous Nela Park, the University of Light. National Carbon and Willard Storage Battery companies, as well as others, make Cleveland an important center in industries centering around various phases of electrochemistry.

Colleges in Cleveland

Cleveland is unique in that it looks largely to its own schools for cultural and scientific training and progress. Western Reserve, with its several undergraduate colleges and various graduate professional schools, provides a wealth of trained leadership for Cleveland, and for the nation as well. Case Institute of Technology is one of the leading engineering schools in the nation while Fenn College has had an outstanding record as a cooperative school in which students may alternately secure periodic classroom and actual business or factory experience. Baldwin Wallace and John Carroll colleges, located in suburban Cleveland, and Oberlin college not far away provide educational programs in somewhat smaller institutions having a closer relationship with church groups. Schauffler college, another Cleveland institution, is unique in its field and trains leaders only in the fields of religious education, music, and social service.

Music, Art, Sports

Severance Hall, home of the nationally famous Cleveland Symphony Orchestra, and the Cleveland Art Museum, with its wooded lagoon and stately formal gardens, add to the beauty of University Circle, and the various parks and parkways in and around Cleveland contribute to the charm of the Forest City.

Home of the 1948 World Champpions, the Cleveland Indians (base-

HOTEL STATLER – CONVENTION HEADQUARTERS

ball) and the 1949 Champion Browns (professional football) as well as the Barons (hockey) and other less well known teams, Cleveland is perhaps one of the most sport-minded cities in the country.

And Cleveland is interested in the theater. In addition to supporting road shows of well-known plays, operas and light operas in season, Greater Cleveland boasts of quite a number of Little Theater groups, some of which provide classes in various phases of theater crafts.

Excellent Travel Facilities

Cleveland is a busy transportation center, served by numerous rail, bus, and air lines as well as by boat during the summer. With nearly half of the entire population of the United States within a 500 mile radius of its varied industries, Cleveland has been referred to as "The Best Location in the Nation." With its many interests in industry, in civic improvement, and in national and international outlook, Cleveland is striving to continue to merit that appellation.

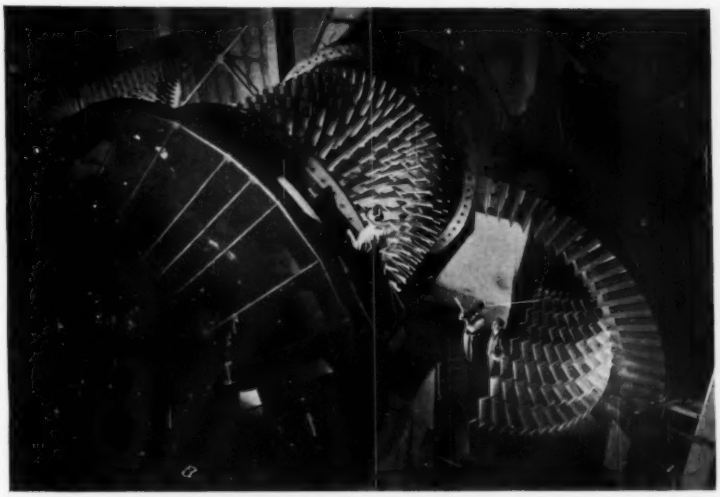
Cleveland Offers Interesting Plant Trips

The committee arranging the plant trips for the Cleveland Convention were especially fortunate in being able to obtain inspection tours of the Lewis Flight Propulsion Laboratory, with all of its most recent equipment in the aircraft field, and the B. F. Goodrich Research Center, likewise outstanding in the rubber industry.

Lewis Flight Propulsion Laboratory

The Lewis Flight Propulsion Laboratory, newest of the three NACA research centers, is situated on 200 acres of land adjoining the Municipal Airport at Cleveland. As the name implies, the Laboratory investigates problems of aircraft power plants and their components, such as compressors, turbines, fuels, lubricants, materials, ducting and propellers. Although in operation since only 1942, this Laboratory is now the world's largest center for research on aircraft propulsion systems. It is also the only facility where full-scale aircraft power plants may be studied under simulated conditions of high-altitude flight. Another feature of the Lewis Laboratory is the icing research tunnel, where investigations are made of the flight characteristics of engines, propellers, and aircraft components under ice-forming conditions. This center also conducts the NACA's all-weather flight research program.

Basic research which will have an important bearing on our country's aviation future is being conducted at the three laboratories of the National Advisory Committee for Aeronautics. Established by the Congress in 1915 to "supervise and direct the scientific study of the problems of flight with a view to their practical solution," NACA today employs over 6,000 research scientists and other workers, in three research centers at Langley Field, Virginia, Moffett Field, California, and Cleveland, Ohio, with coordinating Headquarters at Washington. Dr. Hugh L. Dryden is Director of the NACA and administers the research program.



THE SEVEN-STAGE 18-FOOT-DIAMETER COMPRESSOR OF THE 8 x 6 FOOT SUPERSONIC WIND TUNNEL AT NACA'S LEWIS FLIGHT PROPULSION LABORATORY. POWER REQUIRED 87,000 HP.

In the original plans for the Lewis Laboratory the reciprocating engine and its components were major subjects for investigation. To increase the power output of reciprocating engines, to improve them aerodynamically, to improve their fuels, lubricants and cooling systems, and to provide better propeller design were some of the goals of the research scientists.

Before the Laboratory could be finished we were involved in World War II. Through the war period the Lewis staff turned its efforts to the improvement of fighting aircraft,

many times being diverted from the original objectives of basic research to testing on high priority work requiring maximum effort of the expanded personnel.

War Brought Jet Propulsion

With the war came jet propulsion. It was vital that much of the capacity of the Laboratory be diverted to study of this new type of engine. Today little work at the Laboratory is being done on reciprocating engines, while ever increasing amounts of effort are concentrated on acquiring the scientific data necessary to the design of jet and rocket power plants to be used in the high performance aircraft of tomorrow.

With the broadening use of jet power for aircraft propulsion, scientists looked forward to the next great achievement in flying progress—surpassing the speed of sound in pilot-guided flight. NACA research personnel gave leadership in the attack on this new goal, working closely with the military and the aircraft industry. Intensified research and flight experimentation, at Muroc Air Force Base, resulted in the first supersonic flight when the Bell X-1, rocket-powered research airplane was flown at speeds "much greater than the speed of sound."

Expanded work on the problems incident to supersonic flight included research to obtain the greater and greater powers required for supersonic flight at altitudes up to 80,000 feet and temperatures as low as −70 degrees. This required new tools for research. Typical of the new installations are the twenty-foot-diameter Altitude Wind Tunnel for full-scale power plant research, the Jet Propulsion Static Test Laboratory, the Jet Propulsion Fuels Laboratory, the Rockets Section, and the 8- by 6-foot Supersonic Wind Tunnel, the largest supersonic tunnel in the world.

This newest major installation completed at the Lewis Laboratory is showing itself especially useful in the study of many problems in the higher speed ranges. Similar to all supersonic tunnels at the Lewis Laboratory in that it is of the non-return-passage type, to permit burning fuel and air in the engine under actual operating conditions, the new wind tunnel required several years for its completion. It was first placed in service in the spring of 1949, then calibrated, and now is being used in the production of useful data.

To prevent condensation and velocity disturbances in the test section, air passing through the tunnel must be extremely dry. At maximum operating conditions, as much as 2,000,000 cubic feet of air per minute—weighing almost 75 tons—are drawn into the tunnel. Air is dried by passing through beds of activated alumina, which remove as much as a ton of water each minute on a hot day. From the drying building, the air moves into the inlet of the compressor, which is powered by three electric motors providing 87,000 horsepower and connected in tandem. The air leaves the compressor at pressures up to 1.8 atmospheres but at low velocity, and then is expanded to produce the desired speed in the test section. This speed can be varied from 1.4 to 2 times that of sound.

Supersonic Speeds Reached

The air reaches the speed of sound as it moves into the minimum area of the tunnel, and as the tunnel passage expands, the air accelerates until the desired supersonic speed is reached. The amount of area expansion downstream of the minimum section of the nozzle is controlled by flexing two stainless steel side plates, 35 feet long, 8 feet high, and 1 inch thick. To do the flexing work, 14 hydraulically-operated screw jacks are employed.

This new tunnel provides the first opportunity to study turbojet and ram-jet engines in actual operation at speeds up to twice that of sound, and under the same conditions of temperature and pressure as would be found at 35,000 feet altitude.

Another approach to the quest for sufficient power to propel tomorrow's aircraft at supersonic speeds is the research attack on rocket problems. Its ability to provide super-performance, although for only short periods at the present time, has caused the rocket engine to be used as a primary power plant for military missiles and upper-atmosphere research vehicles.

A major problem in rocket engines is to secure the highest possible thrust from a unit of propellant. Studying this problem, Lewis Laboratory researchers have, both on paper and experimentally in engines and in the laboratory, investigated the extent to which fuels can be improved.

Sections of the Icing Research Tunnel (left) and the Altitude Wind Tunnel (right), at Lewis Flight Propulsion Laboratory.

B. F. Goodrich Research Center

The B. F. Goodrich Research Center was located at Brecksville, about half way between Akron and Cleveland, after an exhaustive study of the basic requirements of a rubber research laboratory. The site includes 261 acres of approximately level ground on a high plateau which affords advantages in favorable contour and natural beauty as well as access to good living conditions and cultural advantages.

The scientific staff of the Research Center is comprised of 100 scientists and approximately 125 nonprofessional personnel.

Laboratory Arrangement Unique

There are five separate buildings making up the Center, an important one of which is the main research laboratory where the basic research is conducted. In this building much emphasis has been laid on the flexibility and arrangement of utilities and equipment. After much study a module was adopted with the dimensions of 10 ft x 26 ft, and provision was made for the installation of removable partitions around each of these modules. If desired, a 10 ft x 26 ft room can be quickly arranged by installing a movable partition around a 10 ft x 26 ft area. The same is true, for example, of a 20, 30, or 40 by 26 ft area. These partitions are flush-type steel in units which can be easily moved and handled and are interchangeable. The ceiling height is 10 ft 6 in. Services such as gas, electricity, water, steam, air, etc., are available every ten feet for each one of these ten-foot wide modules. Thus, the type of research work done today in a module requiring specific type of equipment and services could be changed overnight completely into another type of research work.

The total area provided for each worker, including corridors, services, working space, library, dining rooms, shops, evaluation and testing, totals 560 square feet per employee.

Disposal of Gaseous Wastes

Each of the modules described above is provided with a hood for removal of the gaseous by-products of the laboratory. The hoods in practically all laboratories have previously functioned on the basis that all the air entering them came from the air circulated in the total laboratory space. In an air-conditioned unit, however, this procedure is very wasteful and costly of refrigerated air. The hoods in the Center incorporate novel features in this regard inasmuch as a definite required amount of air is removed from the room by the hoods and the additional air required to make the hoods function satisfactorily is supplied internally. In order for these hoods to operate satisfactorily, it is necessary that 1,200 cubic feet of total air per minute be exhausted from the hoods. Of this total 400 cubic feet is the volume removed from the laboratory and the balance, 800 cubic feet, is the makeup air delivered directly to the inside of the hood. Such dilution of the gases or vapors insures a tremendous factor of safety as regards the health, comfort, and working conditions of the occupants of the laboratory units. Also such dilution renders virtually impossible any contaminating effect of the surrounding outside atmosphere. Without the makeup air principle in the hoods, non-recirculating air conditioning would be virtually prohibitive in cost in such a laboratory.

Provision for Sensitive Instruments and Heavy Machinery

In order to study the properties of materials, especially the physical properties of high polymers, it is necessary to interpret physical and chemical behavior in terms of molecular structure. This involves two different kinds of testing, one with the use of delicate equipment sensitive to vibration and electrical disturbances, the other with the use of equipment which produces such disturbances. Suitable locations in two buildings have been provided for these two types of investigation. Further provision has been made for the isolation of special equipment. Since the walls of the laboratories are of metal, fairly good electrostatic shielding is provided in the structure. Special care has been taken to shield rooms where electrical disturbances are generated. Freedom from vibration has been secured in one of the buildings by extending piers to solid rock.

Modern scientific studies of the structure of matter require highly specialized equipment such as that employed in the study of electron microscopy; x-ray and electron diffraction; dielectrics, over the range

PHOTOGRAPHIC REPRODUCTION OF ARTIST'S PAINTING OF THE RESEARCH CENTER OF THE B. F. GOODRICH COMPANY NEAR BRECKSVILLE, OHIO.

from 10 to 10^{10} cycles/second; light scattering; various types of spectrometry; and nuclear physics equipment for tracer work with Geiger counters, ionization chambers, and a radium source for neutron production.

Library

The present collection of literature in the technical library comprises about 10,000 volumes in the physical, chemical and engineering fields. The nucleus of the collection consists of bound volumes of complete runs of the most important technical periodicals extending back as far as 1788.

Machine and Other Shops

Complete small shops and fabricating facilities are included in the service units of the Center. Machine, carpenter, welding, pipe-fitting, sheet-metal, and electrical shops provide for the construction or erection of highly specialized pieces of experimental equipment necessary in all modern research. These shops are adequately equipped to build pieces of equipment of virtually any required design.

Chemical Engineering Unit

Adjacent to the main research laboratory is the engineering research building. The two buildings are connected by a short corridor for easy intercommunication. In the engineering research building are located the services such as shops, instrument room, boiler room, receiving and stores, air conditioning equipment, water reservoir, cooling tower, plus generous facilities for the processing and curing of rubber and plastics for chemical engineering research.

Chemical Engineering Research

Chemical engineering research has three major functions in its connection with the Research Center. Its first and major job is to carry out basic and fundamental chemical engineering research on design, efficiencies and engineering operations for the various chemical processes; second, to evaluate the basic processes from the main research laboratory; and third, to determine the materials of construction in which these basic processes can be operated.

To carry out these operations, space has been provided for polymerization work and the handling of volatile and dangerous monomers. Also provision has been made for full four-story clearances for vacuum equipment and other equipment requiring high head room. A bridge crane has been installed over this high bay to facilitate the movement of heavy and intricate pieces of chemical engineering equipment.

Process and Product Evaluation

There are two evaluation laboratories designed for specific purposes. One of these is equipped to handle large quantities of materials produced in chemical engineering research so that their behavior in various steps up to full scale manufacturing can be evaluated. This laboratory is equipped with mills of new and improved design, internal mixers, extruders and curing facilities.

Research Compounding

For the evaluation of small quantities of materials which usually are originated in the main research laboratories, a small scale laboratory is equipped with mills, curing and testing equipment for complete physical evaluation, and convenient small scale evaluation.

Hi-Pressure Research

A separate building has been designed and isolated in which to conduct extremely high pressure research. Reinforced concrete barricades with walls one foot thick have been provided to shield and protect the worker from the hazards of this kind of operation. The roof and one wall of the barricade units are of the lightest construction and are designed to yield at relatively low pressure limits. Utmost precautions are taken here to safeguard the workers and the property. Glasses are removed from the gauges, extra reinforcements are provided for all the pipe lines, periscopes are used for reading instruments, and all mechanisms used to operate the reactions are carried through the barricades and made accessible from the outside.

Hi-Vent Building

It is inevitable that the pursuit of some research studies requires the use of volatile materials or gases. Some of these are of inflammable nature, some are irritating to the eyes and respiratory system, while others possess physiological action. The soundest method of handling such materials is to keep their concentration in the laboratory near the zero limit by great dilution with fresh air. No ordinary ventilation system is adequate. For this reason a special highly ventilated laboratory known as the hi-vent building has been constructed at a distance from the main group of buildings. In this space research work on these materials is conducted by technically trained personnel in safety and comfort. A virtual torrent of fresh air is passed through the building continuously. To supply this fresh air to the enclosure requires a very large heating unit to preheat the air for the comfort of the worker in winter months. A plenum is provided under the floor through which all this fresh air is exhausted. It would be virtually impossible when using research quantities of materials for the gases to ever reach a critical concentration. In this type of building research work can safely be done which could not be undertaken in any other type of construction.

Volatile Solvents

Inasmuch as the Research Center depends only upon its own supplies, reasonable quantities of volatile solvents must be stored conveniently at hand. For this purpose a special isolated building has been provided and equipped with sprinklers and fire-fighting systems in which 50-gallon drum quantities of these solvents may be stored with absolute safety.

Activities of the Board of Directors

The following actions were taken at the meeting of the Board of Directors, held in the Office of the Secretary at 235 West 102 Street, New York, N. Y., December 3, 1949.

At the meeting of the Board of Directors held in Chicago, a resolution was passed stating the Society's policy on publication of student theses that have been previously copyrighted or microfilmed. This resolution was not published until the entire Board had had a chance to approve the precise wording, since this is a very important action. This resolution is as follows:

Resolved, that it is the decision of this Board not to publish papers based on student theses previously copyrighted or microfilmed if the microfilm is made available in any manner to the public prior to publication of the papers in the JOURNAL.

* * *

As the entire membership now is aware, the whole policy in regard to publishing has been radically altered. The Board of Directors, therefore, reformed the rate schedule for dues with the thought in mind that after we have had more experience with the new publication, we will be better able to fix dues schedules for the year 1951. With this in mind, the Board agreed to study this rate schedule at the Cleveland Meeting. The present rate schedule is as follows:

Active Member—$10.00
Associate Member—$7.50
Student Associate Member—$2.50

The Constitutional changes that are to be in force January 1, 1950, have required that new membership application blanks be used. All members were advised to destroy their old membership blanks (the pink form), and the Secretary was instructed to mail to each member two new application forms. If any member desires more membership blanks, please contact the Secretary's office. Any application postmarked after December 31, 1949, will be returned to the applicant, along with a new form, and the applicant will be requested to supply the information necessary on the new form.

* * *

At the suggestion of one of our prominent members, the time of the annual business meeting of the Society this spring will be changed. It has been customary to hold the annual meeting Thursday morning at 9:00 A.M., before the first technical session is started. This spring we shall hold the annual meeting after the luncheon, Thursday noon, and it is the hope of all the officers of the Society that a large number of members will attend this annual business meeting.

* * *

The next Acheson Award has been authorized for the fall of 1950 at the Buffalo Meeting. All members are reminded that they may nominate anyone for this honor. The proper procedure is to supply Mr. A. F. G. Cadenhead (Shawinigan Chemicals, Ltd., Shawinigan Falls, Quebec, Canada), Chairman of the Acheson Award Committee, with nine copies of vital information concerning the nominee.

* * *

At the request of the newly-formed Washington-Baltimore Section of The Electrochemical Society, the Board approved a change in meeting schedules. In the spring of 1951, therefore, our annual meeting will be held in Washington, D. C., rather than in St. Louis, Missouri, as previously planned.

* * *

The Board of Directors approved the recommendation of the Editorial Committee for the revised edition of "Modern Electroplating," namely, that John Wiley & Sons, Inc., of New York City, be granted the contract for publishing this volume.

Graduate Research in Ceramics at M. I. T.

The Division of Ceramics at M.I.T. is unique in the fact that it is established on a graduate level only, to provide advanced instruction in ceramic technology. The training of men for research careers associated with the ceramic field is undertaken from the aspect of the fundamental principles of science rather than from a production or trade practice viewpoint. In addition to courses in ceramic technology these students take graduate work in physical and inorganic chemistry, crystallography and x-ray techniques, colloidal chemistry and heat measurements.

Ceramic applications relate closely to fields of electrochemical interests in the field of electrothermics where refractory materials are essential. One electrothermic product, silicon carbide, finds a rapidly expanding use as a refractory in many high temperature applications. The research activities of the M. I. T. Laboratories include available facilities in the range of 1800° to 2800°C for study of thermal conductivity, diffusivity, resistance to thermal shock, mechanical strength, wettability by molten metals, shear properties, etc. Techniques have been developed for the forming and firing of dense, nonporous specimens of these materials.

Formerly the laboratories conducted extensive programs on the development of clay refractories for high temperature service and the development of insulating fire brick, from which has evolved a continuing interest in the fundamental properties of clay. Naturally-occurring clays carry a variety of adsorbed ions necessitating a purification by electrodialysis before a material suitable for fundamental studies can be obtained. The purification is carried out in Mattson cells, which are a three compartment dialysis cell with an insoluble anode (platinum, graphite, etc.). The dialyzed exchangeable ions pass through parchment membranes to

the outer, or electrode compartments where they are removed by a continuous flow of distilled water, leaving in the center compartment a clay suspension with hydrogen ions substituting for the exchangeable bases adsorbed on clays in their natural state.

The Division of Ceramics has twelve graduate students most of whom are engaged in sponsored research problems as half-time research assistants. It is probable that additional assistantships will be available in 1950 as well as opportunities for full-time students. In addition to positions in the ceramic industry, leading laboratories in the electrical field, atomic energy programs, jet engine and gas turbine research, electronics and university teaching now seek recent graduates with this training. Over the past ten years (excluding the war years) the demand for men with graduate training in ceramic technology has exceeded by ten times the number available.

Acheson Medal and Prize

As a reminder to members, nominators of candidates for the Acheson Award must supply the Chairman of the Award Committee, A. F. G. Cadenhead, with *nine* copies of a document giving the full qualifications of the nominee. This material should be sent to Mr. Cadenhead, Director of Chemical Development, at Shawinigan Chemicals Limited, P. O. Box 6072, Montreal, Que., rather than at the address given in the December JOURNAL.

SECTION NEWS

Chicago Section

The Chicago Section and the National Association of Corrosion Engineers held a joint meeting at the Chicago Engineers' Club on December 2nd.

Mr. R. W. Flournoy of the Corn Products Refining Company was the featured speaker of the occasion and chose as his topic "Corrosion Experiences in Corn Refining Process Equipment." Mr. Flournoy's very interesting presentation was illustrated with many photographs and actual samples of various types of corrosion. In the course of his talk the table shown below was disclosed which shows the variation in corrosion rate of types 316 and 304 stainless steel.

Mr. Flournoy stated that in using this table the rate of 3.0 to 5.0 mpy was considered the maximum allowable rate of corrosion for their application to corrosion resistant equipment.

The meeting was well attended and keen interest was expressed in the talk.

J. H. CONOLLY, *Secretary*

Corrosion Rates of Types 316 and 304 Stainless Steel

Test environment	Corrosion rate-mpy		
	Type 316		*Type 304*
Organic acid fermentation	0.02	(A)	0.05
80°–90°F, pH 2.8, 432 hours	0.71	(S)	0.49
Organic acid evaporation	28.6	(A)	24.2
Liquid 210°F, 135 hours	—	(S)	46.5
Organic acid evaporation	0.50	(A)	0.40
Vapor phase 210°F, 135 hours	—	(S)	17.3
Organic acid evaporation	2.01	(A)	25.3
Liquid phase 90°–100°F, 93 hours	18.1	(S)	32.3
Organic acid evaporation	1.36	(A)	1.28
Vapor phase 90°–110°F, 93 hours	9.2	(S)	16.1
Organic acid evaporation	2.10	(A)	11.5
Liquid phase 0.7*N* sulfuric acid 95°F, 87 hours	19.8	(S)	30.0
Organic acid evaporation	1.30	(A)	1.20
Vapor phase 0.7*N* sulfuric acid 95°F, 87 hours	16.8	(S)	8.9
Organic acid crystallization	0.66	(A)	0.04
7% Sulfuric acid 30°–70°F, 500 hours	0.95	(S)	1.25

NOTICE TO MEMBERS

At the direction of the Board of Directors, the Secretary is mailing two new application forms to each member early in February. These new forms, incorporating the recent Constitutional changes, are to replace any old membership blanks (pink forms). If any member desires more membership blanks, please write to the Secretary's office, 235 West 102nd Street, New York 25, N. Y.

Cleveland Section

To take the place of its regular November meeting, the Cleveland Section of The Electrochemical Society joined with local sections of other chemical societies in sponsoring the "First Annual Dinner of the Chemical Profession in Cleveland." As indicated by the title, the dinner was to inaugurate a series of annual affairs of similar nature, designed to bring the entire chemical profession in this area together to enjoy good food and fellowship, and then a talk

LINUS C. PAULING

of general and common interest given by some outstanding member of the profession.

Nearly 300 chemists and their wives and guests participated in this first joint meeting held on November 29. Mr. George W. Heise, former president of The Electrochemical Society, served admirably as toastmaster to introduce the guest of honor and main speaker of the evening, Dr. Linus C. Pauling, president of the American Chemical Society.

In his address, entitled "The Future of the Profession of Chemistry," Dr. Pauling first discussed briefly some of the possibilities which are open to the chemist to improve his material lot. He next reminded the group with vigor of the great social and political rights and obligations of the profession, all too infrequently exercised to best advantage for all. The major portion of his talk was devoted to the role which chemistry may play in the future, as exemplified by its relation to biochemical and medical research.

It came as a distinct surprise to most listeners to hear, for example, that not a single drug administered by the medical profession is understood scientifically in the why's and how's of its functioning. To date all drug effects are found only on empirical trial and error basis and so are not predictable from theory. Here is where chemistry of the future will step in to help overcome lack of precise knowledge as well as the attendant prejudice shown by some professions. Citing one specific example in which he is currently interested, namely, the so-called sickel cell disease, Dr. Pauling demonstrated how chemistry has been able to produce an understanding of the nature of this disease and how, in the future, it may be able to design and predict, from purely theoretical considerations, not only the exact chemical to cure the disease but also the necessary dosage required for the job.

The meeting was highly enjoyed by all attending and the beginning of a fine tradition seems to have been well established.

H. C. FROELICH, *Secretary*

Midland Section

Dr. Alfred E. Ferguson of the University of Michigan, and President of the Society, addressed the members of the Midland Section at its meeting on November 8, 1949, at the Dow Auditorium, Midland.

Dr. Ferguson's topic was "Polarization and Overvoltage" and he presented an excellent review of the fundamentals of this subject, together with a summary of general observations and conclusions derived from his work in this field.

Particular attention was given to the technique used in measuring polarization with emphasis on the need for refinements capable of achieving reproducible results. The instrumentation used by Dr. Ferguson and other investigators was described and discussed relative to its limitations and the significance of the data obtained.

The evening was very much enjoyed by all attending.

H. A. ROBINSON, *Secretary-Treasurer*

San Francisco Section

The San Francisco Section held its second meeting of the 1949–1950 season at the St. Julien Restaurant in San Francisco on November 16, 1949.

The program for the evening consisted of the dinner meeting, followed by two talks on batteries. The first speaker, Mr. F. B. Montgomery of the Hobbs Battery Company, spoke on the production of storage batteries and next Dr. Gerald H. Kissin of Physical Science Associates discussed dry batteries.

Mr. Montgomery's talk, which was well illustrated with colored slides taken during the actual production of storage batteries, followed the various steps required in the manufacture of a storage battery as it is practiced at the present time. The process for the preparation of the lead oxide paste, the construction and arrangements of the grids, the insulation, interconnecting wiring, and testing of battery performance were all commented upon in the order in which they occur in the actual production line.

Dr. Kissin's talk, which was also illustrated with slides, consisted of a discussion of the present thoughts concerning the chemical reactions occurring in a dry battery, the various sources and processes in use for obtaining manganese dioxide, and the various properties peculiar to the types of manganese dioxide used in the production of dry batteries. A graphical illustration of the differences in the manganese dioxides as shown by the use of x-ray diffraction was presented.

Micrographs of several different

types of manganese dioxide were shown and Dr. Kissin commented upon the characteristic peculiarities in physical appearance which are indicative of the type of manganese dioxide most desirable for use in dry batteries.

Both talks were well received as evidenced by the very lively question and answer period which followed.

R. F. BECHTOLD, *Secretary-Treasurer*

Officers of New Indian Section

The first slate of officers of the newly formed Indian Section of The Electrochemical Society is given below:

Chairman—B. K. R. Prasad, Special Officer, Electric Grid Offices, Govt. of Bombay, Foreshore Road, Bombay.

Vice-Chairmen—K. L. Ramaswamy, Deputy Production Superintendent, Govt. of India Fertilizer Factory, Sindhri.

J. Balachandra, Lecturer in Electro-Metallurgy, Indian Institute of Science, Bangalore.

Secretary-Treasurer—T. L. Rama Char, Lecturer in Electro-Chemistry, Indian Institute of Science, Bangalore.

Executive Committee—V. Aravamuthan, Research Assistant in Metallurgy, Indian Institute of Science, Bangalore. Also Chairman of the Program Committee.

Further reports on the progress and meetings of this new section will appear in future issues of the JOURNAL.

EMPLOYMENT SITUATION

Position Wanted

Electrochemist with 14 years experience in electroplating and electroforming desires position with good future. Last six years has had supervision of research and development in precision electroforming field. Age 32 years. Reply to Box 336, c/o The Electrochemical Society, Inc.,

PERSONALS

U. R. EVANS of Cambridge University, England, has recently been elected a Fellow of the Royal Society of London.

R. M. BURNS, Director of Chemical Research at Bell Telephone Laboratories, Murray Hill, New Jersey, has been appointed to succeed J. C. Warner of Carnegie Institute of Technology as Chairman of the National Research Council's Advisory Committee to the Prevention of Deterioration Center.

CHARLES P. ROBERTS, Jr., is now in the Technical Department of the Westvaco Chemical Division, Food Machinery and Chemical Corporation, South Charleston, West Virginia. Mr. Roberts had been in the Research Department of the Westvaco Chlorine Products Corporation.

RUSSELL L. HARDY of the E. I. du Pont de Nemours & Company, Inc., Niagara Falls, New York, is now located at that company's plant in Wilmington, Delaware.

Carl Wagner at M.I.T.

Dr. Carl Wagner, probably best known for his contributions to chemical thermodynamics and the electrochemical theory of oxidation and tarnish, has joined the research staff of Massachusetts Institute of Technology. He will devote most of his time to studies on the thermodynamics of metallic solutions, a project in which he will be associated with members of the Departments of Metallurgy and Chemistry.

Dr. Wagner studied physical chemistry at the Universities of Munich and Leipzig. He received his doctorate at the University of Leipzig in 1924 where he was a student of the well-known electrochemist, Max LeBlanc. In 1934 he was appointed Associate Professor of Physical Chemistry at the Polytechnic Institute of Darmstadt, becoming Full Professor in 1940. He is a former editor of the *Zeitschrift für physikalische Chemie*. Before going to M. I. T., Dr. Wagner was employed by the Ordnance Research and Development Division at Fort Bliss, Texas.

NEW MEMBERS

At the meeting of the Executive Committee held on December 3, 1949, at the office of The Electrochemical Society, Inc., 235 West 102nd Street, New York City, the following were elected to membership:

HAROLD A. GOLLE, Continental Foods, Inc., mailing add: 60 Knapp Avenue, Clifton, New Jersey (Electro-Organic)

HANS B. JONASSEN, Department of Chemistry, Tulane University, New Orleans, Louisiana (Corrosion and Electrodeposition)

ROBERT H. PRICE, Department of Chemical Engineering, University of Cincinnati, Cincinnati 21, Ohio (Theoretical Electrochemistry)

SAMUEL H. REYNOLDS, Great Lakes Carbon Corp., Box 637, Niagara Falls, New York (Industrial Electrolytic)

CLESTER W. SMITH, Superior Metal Co., Box 29, Bethlehem, Pennsylvania (Theoretical Electrochemistry, Organic Electrochemistry, Corrosion and Electrodeposition)

ALFRED H. TAYLOR, JR., Air Reduction Sales Co., Murray Hill, New Jersey (Corrosion)

IRVIN M. WEISS, United Chromium Inc., mailing add: 406 Filmore Avenue, Cuyohoga Falls, Ohio (Electrodeposition)

Reinstatements

ADRIAAN H. W. ATEN, Universiteits-Bibliotheek, Singel 421, Amsterdam, Holland (Electrodeposition, Electronics, Industrial Electrolytic and Theoretical Electrochemistry)

IRVING L. BARKER, Cerro De Pasco Copper Corp., La Oroya, Peru, S.A. (Electrodeposition and Electrothermics)